A BLACK AND WHITE AND COLOR TV VIDEO I-F OUTPUT TRANSISTOR

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ABSTRACT

A new Fairchild silicon planar transistor has been designed specifically to satisfy the requirements of both black and white and color TV video i-f output stages. Characterization of the transistor is discussed with particular emphasis on the parameters important to this application. The use of Y parameters and a study of gain and stability requirements result in a device characterization which directly relates the device parameters to circuit performance. Specific designs of i-f output stages are considered. Other possible applications of this new device are discussed briefly.

INTRODUCTION

Semiconductors are now finding increasing applications in the consumer electronics field. In television in particular, there is considerable interest shown in transistor designs. In order to be able to provide satisfactory performance, economically, it has been found necessary to introduce semiconductors specifically designed for each particular application. The types of devices included in this category are low noise VHF amplifiers, forward AGC 45 Mc/s i-f amplifiers, and high-voltage horizontal scan devices. The device to be discussed in this paper has been developed as a final 45 Mc/s i-f amplifier for both black and white and color TV receivers.

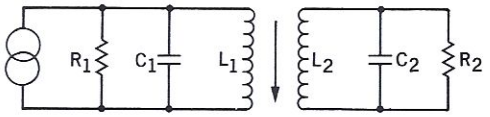
CIRCUIT REQUIREMENTS

Output Impedance

In transistor 45 Mc/s i-f strip the final i-f output circuitry is used to determine, to a large extent, the overall pass-band of the i-f strip. This is primarily the case for black and white TV; while for color TV, sound and adjacent carrier traps are often inserted at this point. In both cases, one of the requirements imposed on the transistor is for a high value of the real component of the output impedance, over the full dynamic operating range, to enable the final output transformer to be designed for mismatch operation. In this way variations of the transistor output impedance have little effect on the overall performance of the stage.

The equivalent circuit for a final i-f output stage transformer is shown in Fig. 1.

FIG. 1 EQUIVALENT CIRCUIT OF A DOUBLE TUNED I-F OUTPUT STAGE



Bandwidth $B = \frac{\omega_0}{\sqrt{2}\,Q_2}$, Coupling Coefficient $K = \frac{1}{Q_2\sqrt{2}}$

Voltage Transfer Ratio $\frac{V_2}{V_1} = \frac{L_2}{2L_1}$, Impedance Transfer Ratio $\frac{R_P}{R_2} = \frac{L_1}{2L_2}$

These expressions are valid for a Transitionally coupled stage with the loaded primary Q_1 much greater than the loaded secondary Q_2.

Where R_1 is the effective parallel resistance for the primary loaded Q, including the output impedance of the transistor R_{22}, R_2 is the effective parallel resistance of the secondary including the load resistance R_L. Where the final i-f is determining the overall response of the i-f, a flat response is required dictating the need for transitional coupling. General expressions for this circuit are:

$$\text{Bandwidth} \quad B = \frac{\omega_0}{\sqrt{2}} \left(\frac{1}{Q_1} + \frac{1}{Q_2} \right)$$

$$\text{Coupling Coefficient} \quad K = \sqrt{\frac{1}{2} \left(\frac{1}{Q_1} + \frac{1}{Q_2} \right)}$$

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Voltage Transfer Ratio

$$\frac{V_o}{V_1} = \frac{1}{\sqrt{2}} \sqrt{\frac{L_2}{L_1}} \sqrt{1 + \frac{Q_2^2}{Q_1^2}}$$

Impedance Transfer Ratio

$$\frac{R_p}{R_2} = \frac{\frac{L_1}{L_2}}{\frac{1}{2}\left(1 + \frac{Q_2^2}{Q_1^2}\right)}$$

Where R_p is the secondary impedance R_2 reflected into the primary. A mismatch design $Q_1 >> Q_2$ gives simplified expressions

$$B = \frac{\omega_o}{\sqrt{2}\, Q_2}, \quad K = \frac{1}{Q_2\sqrt{2}}$$

$$\frac{V_o}{V_1} = \frac{1}{\sqrt{2}} \sqrt{\frac{L_2}{L_1}}, \quad \frac{R_p}{R_2} = \frac{L_1}{2\, L_2}$$

In practice a mismatch ratio of 5:1 for $\frac{R_p}{R_{22}}$ is found to be desirable.

In terms of the Y parameters, the output impedance is given by

$$Y_{OUT} = Y_{22} - \frac{Y_{21}\, Y_{12}}{Y_{11} + Y_s}$$

This implies that Y_{22} and Y_{12} should be small and Y_s be large. In particular, for a perfectly unilateralized stage, Y_{12} can be made zero. In practice, however, fixed neutralization is used which calls for a low well-defined value of C_{12}.

Gain and Stability

The expressions for maximum available gain (MAG), stability limited gain (SLG), and stability factor (K) are now well-known.[1] It is only necessary to present the expressions here and comment on the desired requirements for the final i-f stage.

$$MAG = \frac{|Y_{21}|^2}{4\, g_{11} g_{22}}$$

The MAG should be as large as possible; therefore, g_{22} should be as small as possible and Y_{21} as large as possible.

$$SLG = \left|\frac{Y_{21}}{Y_{12}}\right| \frac{1}{S - \cos^2\left(\frac{\theta_{12} + \theta_{21}}{2}\right)}$$

The SLG should be as large as possible. For a stability factor S = 4 the SLG should be greater than 30 db to give adequate circuit gain at 45 Mc/s. Y_{21} should, therefore, be as large as possible and Y_{12} as small as possible.

$$k = \frac{2\, g_{11} g_{22} - R_e\left(Y_{12} Y_{21}\right)}{\left|Y_{12} Y_{21}\right|}$$

For $k > 1$ the circuit will be unconditionally stable so a desired feature would be to have $k > 1$. However, it is still possible to meet all stability and gain requirements if $k < 1$.

In terms of Y parameters, we now have the situation where we require the following important conditions to be simultaneously satisfied.

g_{22}	as small as possible
g_{12}	as small as possible
C_{12}	as small as possible
$\lvert Y_{21}\rvert$	as large as possible

POWER OUTPUT REQUIREMENTS

The requirements for output signal level and load impedance vary considerably from receiver to receiver. For black and white, a detected video output of 3 volts into a 3-K load is fairly typical. Consideration of these requirements leads to a quiescent bias of 10 volts at 10 mA on the final i-f stage.

For color TV higher output powers are required because some hybrid receivers require a transistor i-f to supply the same signal and impedance level previously driven by a tube. For these applications 20 volts at 15 mA is required.

These two conflicting requirements have resulted in two different packages: an epoxy package SE5025 for the lower power black and white requirements and a TO-5 metal can 0063 for color requirements. Although the same transistor chip is used in both cases, the extra power dissipation for the metal can is achieved at the expense of increased feedback capacitance.

OTHER IMPORTANT PARAMETERS

The breakdown voltage LV_{CEO} must be greater than 45 volts to allow for full signal excursion.

Beta linearity should be good up to currents of 40 mA to ensure linear amplification of the video signal.

Figure 2 lists the important parameters and the desired values for final i-f operation.

FIG. 2 IMPORTANT PARAMETERS FOR A TRANSISTOR FINAL TV I-F STAGE

Operating conditions - 10V, 10mA, 45 Mc/s

Parameter	Symbol	Design Limit
Output Resistance	$R_{22} = \frac{1}{g_{22}}$	>5K
Feedback Capacitance	C_{12}	<1pf
Common Emitter Unity Gain Frequency	f_t	500 Mc/s Typ
Common Emitter DC Current Gain	h_{FE}	>20
Common Emitter Breakdown Voltage	LV_{ceo}	>45 Volts
Maximum Available Gain	M.A.G.	>36dB
Stability Limited Gain	S.L.G.	>30dB
Stability Factor	k	0.8 Typ

Transistor Design

We now proceed to realize the desired parameters in the transistor. Many of the desired parameters relate to other more readily controlled and more readily measured parameters such as f_T, BV_{CBO}, BV_{EBO}, h_{FE}, and LV_{CEO}.

Geometry

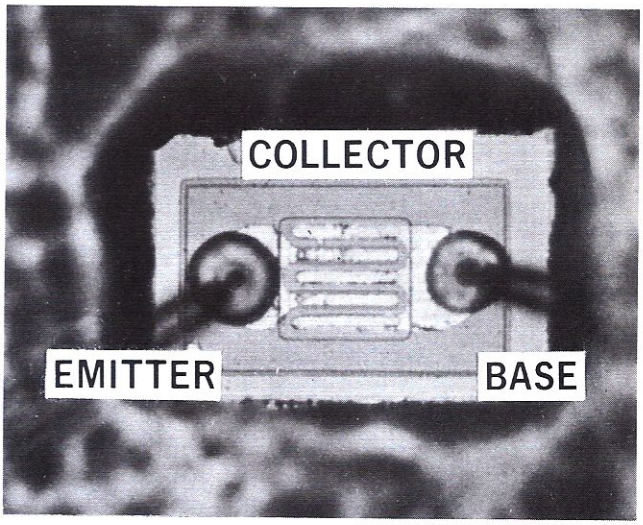
The requirement for a small C_{12} dictates a small base area and a high collector resistivity. Since the circuit requirements include large signal operation (overload condition), the large series collector resistance of a high resistivity collector would be undesirable. This resistance is minimized by using a wafer with a low resistivity substrate and a high resistivity epitaxial layer.

If the epitaxial resistivity is too high, the collector series resistance becomes excessive; a good compromise between collector series resistance and transfer capacitance is an epitaxial resistivity corresponding to a BV_{CBO} breakdown of 100 volts.

The signal overload condition, with peak currents of 30 mA, requires a minimum emitter area of 6 square mils (1.0 mil = 0.001 inch) so that current density does not exceed 5 mA per square mil. Using a 0.7-mil wide emitter stripe, the emitter area requires 8 mils of stripe length. This has a poor aspect ratio for one stripe, so two emitter stripes were used. The 20-square mil area of the base was determined by the width and number of base and emitter stripes, the inter-stripe spacing, and the space from the outside edges of the stripe cutouts to the edge of the collector base junction.

Figure 3 shows the transistor die. The stripe geometry gives the high ratio of emitter periphery to emitter area (approximately 3.3:1) which is required for r-f devices. The planar process is used because of its mass production capabilities, reliability, repeatability and economy.

FIG. 3 PHOTOMICROGRAPH OF TRANSISTOR CHIP



Electrical Parameters

From this starting point, the base and emitter diffusions are determined by considering the interrelationships of the remaining important parameters. The transfer capacitance correlates fairly well to BV_{CBO}, which is a measure of collector resistivity. The correlation is imperfect because breakdown first occurs near the edge of the collector-base junction, while the region of interest is the area beneath the base, which contributes to most of the transfer capacitance. The resistivity of this region correlates very well with the transfer capacitance, but this resistivity is difficult to determine by breakdown voltage when breakdown occurs at a lower voltage near the edge of the junction. This phenomenon is characteristic of diffused junctions. It occurs because either

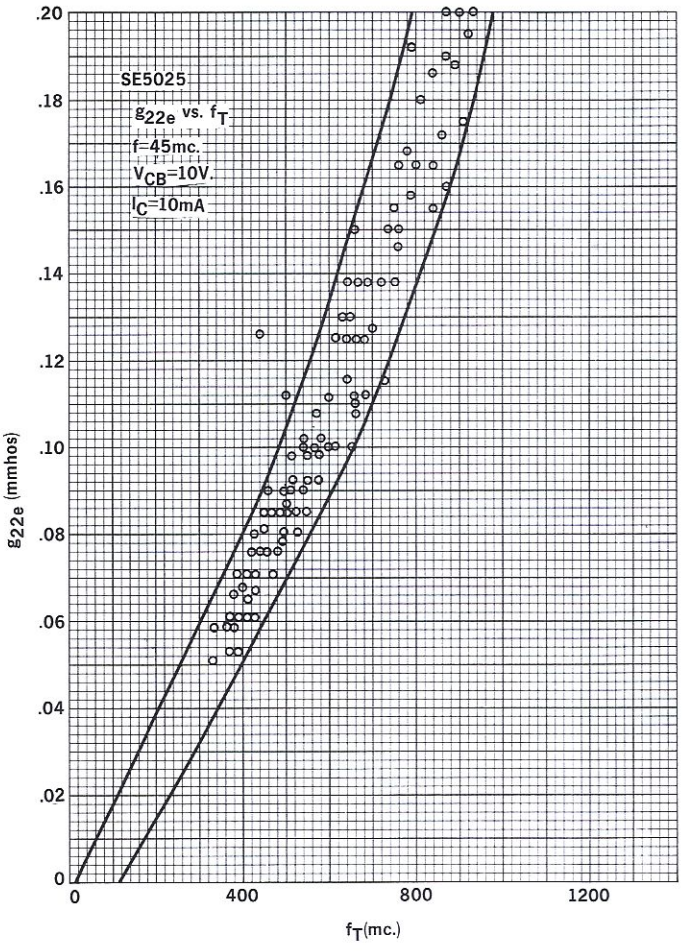
1) the radius of curvature of the junction near the edge of the junction is short enough to increase the electric field or 2) the graded junction is such as to cause a higher electric field. The higher electric field lowers the junction breakdown voltage.

The output conductance g_{22} should be as small as possible. It correlates to several parameters, the most important being f_T.

Figure 4 shows the correlation of g_{22} vs f_T for devices from several runs with similar diffusions. Thus, the lower we make f_T, the smaller g_{22} becomes. Also, g_{22} is related to h_{22} by

$$g_{22} = R_e \left[h_{22} - \frac{h_{12} h_{21}}{h_{11}} \right]$$

FIG. 4 CORRELATION OF g_{22e} AND f_T

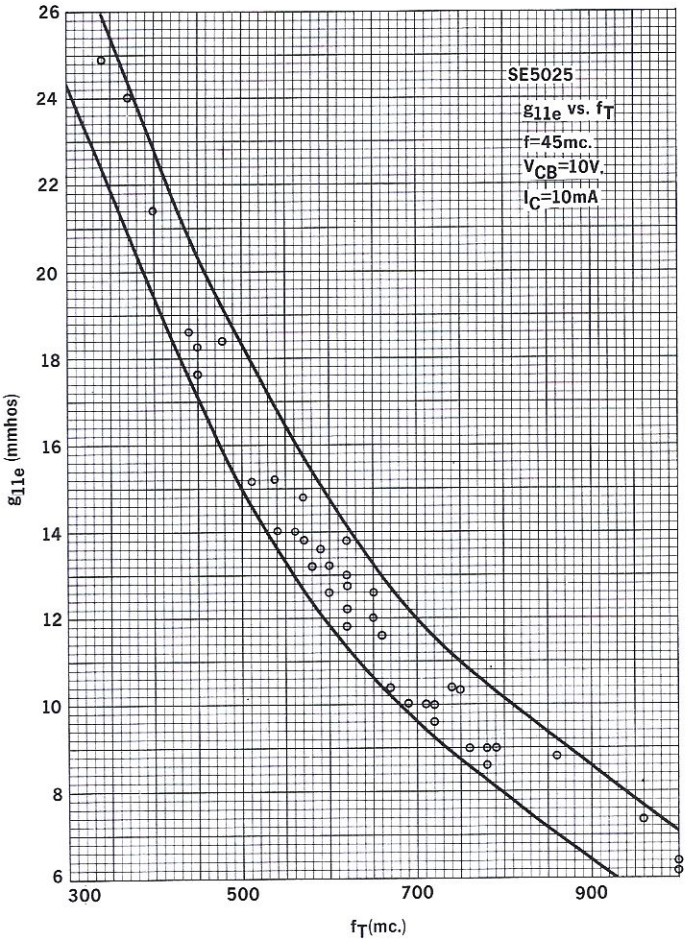


On the common emitter characteristic curve family (as seen on a transistor curve tracer), the slope of a constant base current line is the low frequency value of h_{22} at that point. Since h_{22} at low frequency is proportional to h_{22} at r-f, low g_{22} requires low h_{22}, though the correlation is poor.

For low values of g_{22} throughout the operating region, the curve tracer slope of constant I_b lines should be fairly flat along the r-f load line. Flatness of the characteristic family load lines is assisted by keeping I_{CEO} low and by diffusing so that the LV_{CEO} breakdown is at least 20% higher than the highest expected instantaneous collector voltage.

The input conductance g_{11} correlates to f_T, as shown in Fig. 5. It is desirable that the spread of g_{11} be fairly tight, which in turn requires a tight limit on f_T. It is also desirable that g_{11} have a small value, which requires a high value of f_T. Thus, the f_T requirement must be compromised with the f_T required for low g_{22}. In addition, the (oscillation) stability, as expressed by k factor, is improved as f_T is made smaller. From these considerations, the optimum value of f_T is 450 Mc.

FIG. 5 CORRELATION OF g_{11e} AND f_T



The base and emitter diffusions are chosen to give this value of f_T and reasonable DC h_{FE}.

For the small value of transfer capacitance of the SE5025, die metallizing and packaging are more important than for

larger devices. The base metallizing bonding pad area is small to reduce its contribution to transfer capacitance. Finally, the completed die is mounted in Fairchild's low-capacitance epoxy package.

In consideration of the preceding discussion, the following specifications in Fig. 6 have been selected for the SE5025 at V_{CB} = 10 V, I_C = 10 mA, f = 45 Mc.

FIG. 6 PARAMETERS FOR THE SE5025

Symbol	Common Emitter Parameters	Min.	Typ.	Max.	Unit
g_{11}	Short circuit input conductance	9	15	27	mmho
C_{12}	Short circuit reverse transfer capacitance	0.7	0.83	1.0	pf
$\|Y_{21}\|$	Short circuit forward transfer admittance magnitude	160	180	220	mmho
θ_{21}	Short circuit forward transfer admittance phase		-40		degrees
g_{22}	Short circuit output conductance	30	90	200	μmho
f_T	Current gain-bandwidth product	300	450	700	Mc
MAG	Maximum Available Gain		38		db
k	Stability factor		0.8		- -
SLG	Stability Limited Gain		31		db
h_{FE}	DC Current gain	20		100	- -
LV_{CEO}	Collector-emitter sustaining voltage	45			Volts
BV_{CBO}	Collector-base breakdown voltage	60			Volts
P_d	Power dissipation at 25°C ambient			250	mW

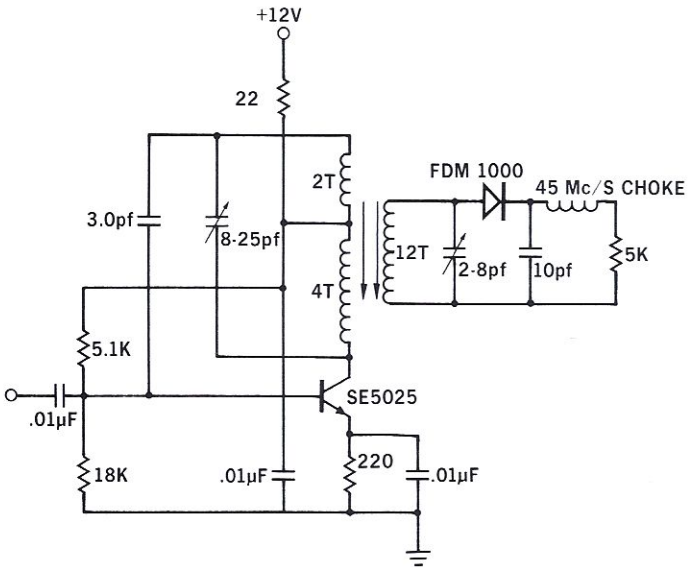
TYPICAL FINAL I-F STAGE CIRCUITS

Black and White

The schematic shown in Fig. 7 is representative of the final 45 Mc/s i-f stage of a black and white receiver using a double tuned transformer to provide the desired i-f bandshape.

The circuit is designed to reflect a collector load of 1 KΩ ensuring a mismatch ratio of at least 5:1. Fixed neutralization is provided and the coupling between primary and secondary can be easily adjusted to give the desired transitional coupling.

FIG. 7 TYPICAL BLACK & WHITE 45 Mc/S FINAL I-F STAGE



Typical Circuit Performance

Voltage Gain:	(45 Mc/s input, 80% modulated/detected video output) 30 db
Maximum Available Video Output:	8 V peak-to-peak
Typical Gain Variation:	1 db
Bandwidth:	4 Mc/s
Typical Bandwidth Variation:	0.2 Mc/s

NOTE: The gain and bandwidth variations quoted are due to changing devices after circuit alignment.

Color

The schematic shown in Fig. 8 for a final i-f in a color receiver is rather more complicated than the black and white circuit. Additional sound traps are incorporated in the video detector circuit and a sound detector is taken directly from the collector. The additional traps and bandshaping give a final overall i-f response shown in Fig. 9. The chroma subcarrier is 6 db down, ensuring effective sound trapping without affecting the chroma phase response.

FIG. 8 TYPICAL COLOR 45 Mc/S FINAL I. F. STAGE

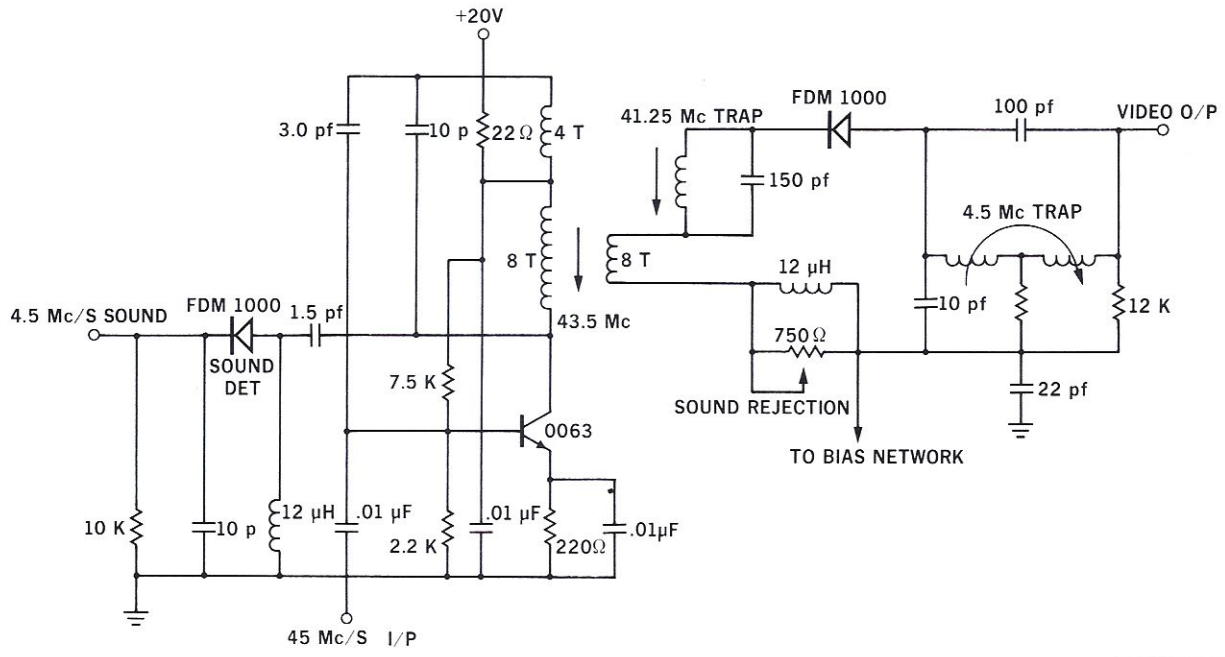
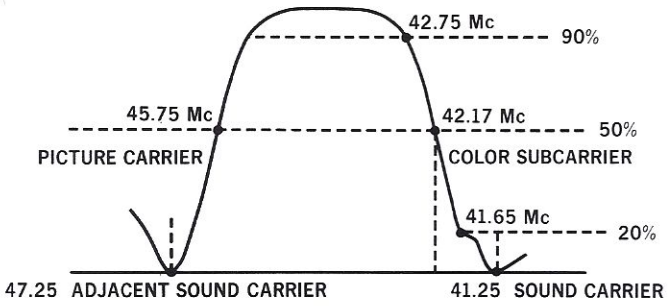


FIG. 9 COLOR I-F RESPONSE



Additional Applications

The high output impedance, high stable gain, high breakdown voltage, low feedback capacity and low saturation voltages make this new device ideally suited to many applications in the consumer field. The following list gives some of the potential consumer applications:

AM 455 Kc/s i-f amplifier

FM 10.7 Mc/s i-f amplifier

Non-neutralized 3.58 Mc/s amplifiers in TV color processing circuits

3.58 Mc/s oscillator

TV sync take-off and amplifier circuits

Wideband video amplifiers

CONCLUSION

A highly satisfactory device that meets all the requirements of the final 45 Mc/s i-f stage has been developed. The inherent properties of the device as a linear high-frequency amplifier also make it suitable for many other applications.

ACKNOWLEDGEMENTS

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REFERENCES

1. Selig Gertzis and Robrecht Bosselaers, "Characterization of R-f Transistors for AM/FM Radio Applications," IRE Transactions on Broadcast and Television Receivers; Vol. BTR-8; November, 1962.